Spatial Evaluation of Potential Tsunami Vertical Evacuation: A Case Study of the Western Coastal Belt in Sri Lanka

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Abstract

On December 26, 2004, a massive earthquake occurred near the coast of Sumatra, Indonesia, and it was the worst tsunami incident ever recorded in the Indian Ocean. Fourteen countries were affected by this hazard, and four countries—Indonesia, India, Sri Lanka, and Thailand—were severely damaged. The recorded death toll was more than 35,000, and approximately one million people were affected in Sri Lanka. After this tsunami incident, Sri Lanka was also categorized as a tsunami-vulnerable country. Several past studies have contributed to introducing proper mechanisms that would minimize the damages from the next tsunami incident. Most tsunami-vulnerable areas have been covered by horizontal tsunami evacuation based on the elevation profile of the area. However, in Sri Lanka, people need to travel great distances to reach tsunami evacuation centers due to the lower elevation profile of the coastal area.

The purpose of this study was to spatially evaluate the potential for tsunami vertical evacuation in the western coastal belt in Sri Lanka. The Moratuwa Municipal Council Area (MMCA) was selected for this case study by considering the existing urban structure and the tsunami vulnerability of the western coastal belt. Several criteria and assumptions have been computed to achieve the goal of the study. A geographic information system (GIS), remote sensing (RS), and demographic data facilitated the completion of the following tasks: (i) preparation of three tsunami scenarios based on the 2004 tsunami experience; (ii) updating the building layer and calculating the building height and volume by using airborne light detection and ranging (LiDAR) data; (iii) calculating the inundation ratio building volume loss, available building volume, and nighttime population; (vi) identifying the tsunami vertical evacuation sites based on the existing urban spatial structure; (vii) estimating the maximum capacity of the selected vertical evacuation sites using a usable building volume index (UBVI) and volume

determination factor (VDF); and (vii) calculating tsunami arrival time, distance and time from resident place to evacuation centers in three tsunami scenarios.

The MMCA is located in the south direction of the Colombo district and is the fifth largest municipal council in Sri Lanka with a total population of 168,280 as of 2012. The MMCA has unique physical characteristics as it is a natural peninsula covered by complex water bodies such as the Indian Ocean, Bolgoda Lake, and Lunawa Lagoon. In 2004, the Indian Ocean tsunami affected both life and property in the MMCA. The development pattern of the MMCA will denote significant damages in the next tsunami disaster. Several tsunami horizontal evacuation centers have been identified inside the MMCA, but most of them are located away from the coastal belt. The residents need to travel long distances to reach a safe location, and it is a challenging task, especially in nighttime tsunami events. Thus, a nighttime tsunami incident was selected by considering current evacuation procedures and the tsunami vulnerability of the study area. Identifying potential vertical evacuation sites near residential areas will benefit the residents for effective tsunami evacuation. Hence, it is necessary to study the potential of vertical tsunami evacuation to provide more alternatives to evacuate during nighttime tsunami disasters.

In this analysis, three tsunami scenarios—4 m, 8 m, and 12 m—were used to identify potential vertical evacuation sites. According to the results of the inundation ratio, the category of critical buildings can be increased to 1.7% and 67.0% in 4 m and 12 m scenarios, respectively. It was indicated that the 12 m scenario consisted of more damage than the other two scenarios. Regarding the evacuation sites, 220, 232, and 122 were selected for the 4 m, 8 m, and 12 m scenarios, respectively.

VDF was used to calculate the UBVI of each building to demarcate the capacity of each selected site. The VDF was calculated based on expert knowledge and fieldwork by considering

the types of buildings, primary usage and building volume. According to the calculations of the capacity of each site, the selected 220 sites will facilitate 17,594 people during the 4 m tsunami scenario. The selected 232 sites will accommodate 25,677 people during the 8 m scenarios. All selected sites are capable of accommodating the affected population in both the 4 m and the 8 m scenarios. However, the selected evacuation sites are not sufficient for accommodating the affected population in the 12 m scenario. In the 12 m scenario, 12,221 people are affected. However, the evacuation sites can only accommodate 10,165 people.

The finding of vertical evacuation by considering the existing urban structure of the city is essential to save human lives during the next tsunami incident. The adopted methodology can be used as an example for other lowland coastal cities to select vertical evacuation to protect human life. The selected evacuation of the MMCA area provides vital information for a comprehensive tsunami evacuation plan in the future. In addition, the use of the UBVI and the VDF to calculate an accurate number of people who can be accommodated in the evacuation sites is important in the tsunami research field. Most previous researches used whole available building volume for capacity calculations. However, each building had been established based on a specific objective. The application of the VDF and the UBVI provides the real picture of the capacity of the evacuation sites. It can be used as a proxy indicator in future tsunami vertical evacuation calculations.

This study contributes to the use of existing urban structures to identify vertical evacuation sites based on three tsunami scenarios. The capacity estimation was done based on the newly proposed two indexes (UBVI and VDF), and this methodology can be used as a reference methodology in future tsunami vertical evacuation studies for different locations, especially lowland coastal cities to produce similar results. This study's approach combines several methods based on the GIS platform. The results can be used as proxy indicators for

policymakers and disaster planners to provide adequate evacuation plans in vulnerable coastal communities.

Keywords: tsunami scenario, DSM, DTM, building volume, VDF, UBVI, Moratuwa Municipal Council area, vertical evacuation, nighttime population, tsunami

Table of Contents

List of Figures

List of Tables

Abbreviations

MMCA	Moratuwa Municipal Council Area
CBD	Central Business District
GIS	Geographical Information Systems
RS	Remote Sensing
DSM	Digital Surface Model
DTM	Digital Terrain Model
DHM	Digital Height Model
VDF	Volume Determination Factor
UBVI	Usable Building Volume Index
MCDA	Multi-criteria Decision Analysis
UV	Urban Volume